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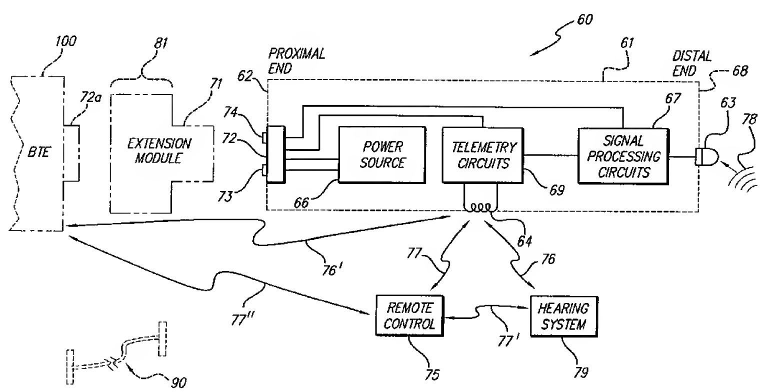
(54) **Title:** A MICROPHONE MODULE FOR USE WITH A HEARING AID OR COCHLEAR IMPLANT SYSTEM



(57) **Abstract:** A microphone module (60) is shaped for insertion into a tunnel (40) made through the soft tissue that connects the retro-auricular space (50) with the ear canal (30). A hollow tube (44) may first be chronically or acutely implanted in such tunnel, and the microphone module inserted into the tube. The microphone module contains a microphone (63) located on the distal part (68) of the module close to or inside the ear canal. In some embodiments, a battery or other power source (66) that powers the module, and signal processing circuitry (67) may also be included in the module. In yet other embodiments, the module may include telemetry circuitry (64, 69). In some embodiments, a behind-the-ear (BTE) speech processor connects to a proximal end of the microphone module. Electrical signals produced by the microphone in response to sensed sound waves may be processed, if needed, by the signal processing circuitry, and provided (via telemetry or physical connections) to the BTE speech processor, or other external or implanted hearing aid component, for use by a hearing system (79), e.g., a cochlear implant system, of which the component is a part. The hearing system may be an external, partially implanted, or fully implanted hearing system, such as a cochlear implant system.

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A MICROPHONE MODULE FOR USE WITH A HEARING AID OR COCHLEAR IMPLANT SYSTEM

Background of the Invention

The present invention relates to hearing aid systems, and more particularly to a microphone module adapted for use with such systems and components of such systems.

One challenge associated with partially or fully implantable cochlear implant and bionic ear systems, as well as other implantable or partially implantable hearing systems, relates to the location of the microphone. Historically, the microphone location for cochlear implants is in a headpiece that is worn on the side of the head, or in a Behind-the-Ear (BTE) hearing aid shell. Neither provides a location for the microphone that takes advantage of the shadow effect of the pinna or the shape of the ear canal, and neither addresses the desire to eliminate visibility of the microphone. The problem becomes even more severe when additional sound signal processing methods requiring multiple microphones are added to the functionality of cochlear implant systems (e.g., beam forming).

For instance, current cochlear implant and bionic ear systems, as well as some models of partially implantable hearing aids, employ sound processors that are worn behind the ear (i.e., BTE processors). They contain a microphone, commonly located beneath or below an ear hook that extends over the top of the pinna in order to hold the processor in place behind the pinna, and they send a processed version of the microphone signal to the implanted part of the system (for instance, via a headpiece on the side of the head), usually together with operating instructions and/or power for the implanted electronics.

The location of the microphone on the BTE or headpiece creates several disadvantages: (1) the shadow effects of the pinna, and other beneficial acoustic effects provided by the pinna and the ear canal, are lost; (2) the microphone location on the headpiece or BTE creates susceptibility to wind noise; (3) telephone use is difficult with such microphone locations.

It is known in the art to connect a microphone to a BTE sound processor via a special ear hook or pliable wire attached to the front tip of an ear hook. Such connected microphone is then positioned so as to be located in front of the ear canal and partly shadowed by the pinna. See, e.g., U.S. Patent Application Serial No. 09/785,629, filed 2/16/2001; and U.S. Patent Application Serial No. 09/927,130, filed 08/10/2001; which applications are assigned to the same assignee as is the present application. The '629 and '130 applications are incorporated herein by reference.

It is also known in the art to use an implantable microphone. For example, one type of implantable microphone known in the art has been developed by IMPLEX AG for use with an implantable hearing aid. Such microphone is disclosed in U.S. Patent 5,814,095, and a fixation element therefor is taught in U.S. Patent 5,999,632, which patents are incorporated herein by reference. The microphone taught in the '095 patent is located in the bony wall behind the skin that lines the ear canal. Placement of this microphone requires a complicated surgical procedure. Moreover, because of the location where the microphone is implanted, the microphone poses the risk of eroding the skin of the ear canal. Furthermore, the thickness of the skin flap over the microphone impacts frequency response of the microphone and causes potential performance variability across users.

Another type of implantable microphone is disclosed in U.S. Patent Application No. 09/854,420, filed 05/11/2001, assigned to the same assignee as is the present application. The '420 application is also incorporated herein by reference.

It is also known in the art to connect the retro-auricular space (space behind the pinna of the ear) to the ear canal via a hollow titanium tube that is permanently placed into soft tissue. See, e.g., United States Patent 6,094,493, which patent is incorporated herein by reference. In one embodiment of the ‘493 patent, an amplification hearing aid is connected to the proximal (retro-auricular) end of the tube, whereby the hearing aid is located behind the pinna of the ear and a transducer sends the amplified sound signal through the tube into the ear canal. Such approach places the

microphone in the retro-auricular space, where it is not very visible, but also where it cannot sense sound as effectively as it could if it were in the ear canal. This concept has been commercialized by Auric® Hearing Systems, Inc. of Charlotte, NC as the RetroX technology. In another embodiment of the '493 patent, the microphone is positioned at the retro-auricular end of the tube, and the transducer, electrical and electronic components are installed in the tube. Once again, the microphone is not very visible, but is still positioned in the retro-auricular space where it cannot sense sound as effectively as it could, were it in the ear canal.

In U.S. Patent No. 5,430,801, the use of a silicone tube is disclosed to direct the output of a conventional hearing aid, held in place behind the ear using an ear-hook or via a piercing through the cartilage of the pinna, into the ear canal. One embodiment disclosed in the '801 patent contemplates placing the distal end of the tube in the middle ear to achieve better gain. However, such embodiment, like all middle-ear devices, involves a significant surgical procedure, and the risk of infection is much greater than a simple piercing of the soft tissue behind the ear. Further, the microphone associated with the hearing aid disclosed in the '801 patent is held at the front of the pinna, either as part of the piercing or connected to the hearing aid through an earring-type coupler. While the microphone placement is thus more favorable than some other approaches, the microphone is visible and tends to be obstrusive.

It is thus seen that what is needed is a microphone that can be used with a BTE sound processor or other components of a hearing system, whether a cochlear implant system or a conventional hearing aid system, that can be easily positioned for effective detection of sound waves (e.g., without the need for extensive and risky surgery); readily removed as required in order to make repairs or to replace or recharge batteries, if used; and that remains essentially invisible or hidden.

Summary of the Invention

The present invention addresses the above and other needs by providing a microphone module shaped for insertion into a tunnel made through the soft tissue connecting the retro-auricular space with the ear canal. Such "retro-auricular-space-to-ear-canal" tunnel (or "ear-canal-to-retro-auricular-space" tunnel) is an important feature of the present invention because it not only provides a physical location where the microphone module may reside when carried by a user, but also keeps the microphone module essentially hidden when in use.

The microphone module of the present invention includes a microphone and associated electronic circuitry to process and/or transmit sound signals sensed through the microphone to a hearing aid, cochlear implant or other sound-processing system with which a microphone is used, such as a Behind-the-Ear (BTE) sound processor. For instance, in some embodiments of the present invention, the proximal end of the microphone module, which exits from the tunnel into the retro-auricular space, may be detachably connected directly to a BTE sound processor (so that the BTE sound processor effectively becomes an extension of the microphone module), or it may be connected by way of a flexible cable, or (in other embodiments) it may be connected by way of a wireless link. The microphone module may further include its own power source, e.g., a battery, which may be replaced and/or recharged, as required. The microphone module may be coupled in various ways to the hearing aid, cochlear implant, BTE or other sound-processing system, such as through a cable, direct connection, or wireless connection, e.g., a radio frequency (RF) link.

The microphone module is very small so it can readily fit within the retro-auricular-space-to-ear-canal tunnel. Its small size is made possible by taking advantage of the smaller batteries (or other power sources), miniaturized RF transmission circuitry (when used), and advanced mechanical design capabilities now available.

In one embodiment, a chronically implanted tube is first placed in the retro-auricular-space-to-ear-canal tunnel, and the microphone module

of the present invention snugly fits inside the tube. In some embodiments, the tube is coated with a film or layer of steroid(s) or other drug(s) that, over time, minimize the risk of infection and/or inflammation.

In another embodiment, an acutely implanted tube, which may be coated with a steroid(s) or drug(s), is placed in the retro-auricular-space-to-ear-canal tunnel, and the case of the microphone module of the present invention snugly fits inside the tube. After a suitable time, the tube may be removed and the microphone module, which may be coated with a steroid(s) or drug(s), placed directly into the tunnel.

In yet another embodiment of the invention, the microphone module, housed in a flexible or rigid tube-like casing, is snugly inserted into the retro-auricular-space-to-ear-canal tunnel, with the microphone located at a distal end of the module so as to be near the ear canal, and with, optionally, a second microphone, connector(s), and/or switch or adjustment control, being located at a proximal end of the module. In alternative embodiments, such optional second microphone, connectors, and/or switch controls may be located in an extension of the module that may be optionally attached to the proximal end of the microphone module.

The microphone module of the present invention provides one or more of the following benefits, among others: (1) a primary microphone location at the distal end of the module close to or inside the ear canal for improved and consistent sound quality; (2) the visibility of the microphone is reduced or eliminated; (3) surgical and medical risk is minimal; (4) the ability to add a secondary microphone at the opposite end of the module for beam forming or other purposes is facilitated; (5) easy use of the telephone; (6) reduced susceptibility to wind noise; (7) improved aesthetics, for instance, when used with a BTE, whereby the microphone module can hold or help hold the BTE in place, thus reducing or eliminating the need for an ear hook; (8) the availability of additional space for electronics or battery that does not add visible bulk to the hearing aid; (9) an easy way to acquire the signal via dual microphones, where a second microphone is located on the BTE (or other hearing aid component, such as a microphone attached to the user's

clothing) or at the proximal part of the microphone module of the present invention, without burdening the aesthetics of current hearing aids.

The microphone module of the present invention includes one or more of the following, but is not limited to:

(1) use of a tube connecting the retro-auricular space to the ear canal;

(2) use of a tube that may be cylindrical, oval, rectangular, or other shape;

(3) use of a tube that may consist of several parts that connect together to allow easy surgical placement, whereby the overall length of the tube may be variable;

(4) use of a tube wherein all or part of the tube may be hollow;

(5) use of a tube that is made of biocompatible material, such as ceramic, stainless steel, titanium, Teflon, silicone, or a polymer of any other kind;

(6) use of a tube that is made of a material that is preferably transparent to RF and/or other signal transmissions;

(7) a microphone module that is shaped such that part, most, or all, of the module fits inside the "retro-auricular-space-to-ear-canal" tunnel, described above, or the tube that is placed in such tunnel;

(8) the possibility of using an optional proximal extension to the module that resides behind the pinna;

(9) a microphone module that contains some or all of the following components: (a) one or several microphones; (b) an RF transmitter or transceiver (for both sending and receiving RF signals) circuit; (c) a battery or other power source; (d) processing electronics, potentially including beam forming capability; (e) external input connector(s); and (f) control switch(es) or adjustment(s);

(10) a microphone that is located at the distal side or end of the microphone module, close to or inside the ear canal;

(11) a second microphone that may optionally be located at the proximal side or end of the module, in a proximal extension of the module, or otherwise connected to the module or hearing aid;

(12) switch(es) or adjustment control(s) that may optionally be located at the proximal part or extension of the module;

(13) a connector(s) that may optionally be located at the proximal part or extension of the module;

(14) a connector that may optionally be located at the proximal part or extension of the module to which a BTE sound processor unit may be detachably connected;

(15) an RF transmitter or transceiver that is located in the module to transmit and/or receive signals to and/or from a hearing aid or hearing aid components, either implanted in the body or in an external location;

(16) a wireless link with the module and/or extension that may be either unidirectional or bi-directional;

(17) a module containing its own microphone and wireless RF links that can replace and/or supplement the function of the headpiece used with a cochlear implant system, which headpiece sends data and operating instructions to the implanted part of a cochlear implant system;

(18) the use of RF signals that may be coded such that only a designated target device will receive the signal;

(19) the use of an optional primary battery within the module or module extension to power the microphone module;

(20) use of an optional rechargeable battery, or some other replenishable power source, within the module or module extension to power the microphone module;

(21) use of a rechargeable battery or other power source that can be recharged inductively through the housing of the module;

(22) use of electronic or signal processing circuits within the module to supplement or replace the circuits within a BTE processor or

other hearing aid component, thereby allowing the bulk or volume of the BTE or other hearing aid component to be reduced.

The microphone module provided by the present invention is preferably encapsulated or carried in an elongate tubular housing, or plug, that is adapted to snugly slide into the implanted tube or retro-auricular-space-to-ear-canal tunnel. Such construction facilitates insertion and removal of the module into and from the tube or tunnel for the purpose of replacing or recharging the power source, or replacing the module with a new module.

In accordance with one aspect of the invention, users of the microphone module would have at least two such modules – one module which is inserted into the retro-auricular-space-to-ear-canal tunnel or tube, and which provides the microphone function of the invention; and at least one other module that serves as a spare. The power source of the spare module(s) may advantageously be replaced, replenished or recharged when not in use.

In accordance with another aspect of the invention, the microphone module allows a BTE unit to be both electrically and mechanically attached to the module as it resides in the tunnel or tube, thereby eliminating the need for an ear hook on the BTE unit to hold the BTE unit in the retro-auricular space. The module, possibly with extension, may take on other functions of a cochlear implant or other hearing aid, such as one or more functions of a headpiece and/or BTE unit of a cochlear implant system.

Brief Description of the Drawings

The above and other aspects of the present invention will be more apparent from the following more particular description thereof, presented in conjunction with the following drawings wherein:

FIG. 1 schematically shows the location of a tunnel made through soft tissue to connect the retro-auricular space with the ear canal, and wherein, in one embodiment, a chronically implanted tube may be placed in such tunnel;

FIG. 2 depicts the end of the tunnel as it opens to the retro-auricular space behind the pinna;

FIG. 3A shows the outline of a tube that may, in some embodiments, be inserted into the ear-canal-to-retro-auricular-space tunnel;

FIG. 3B shows the tube of FIG. 3A coated with a steroid or drug;

FIG. 4 depicts the space behind the pinna, as in FIG. 2, but with the microphone module of the present invention inserted into the tunnel so that a proximal end of the module is positioned in or near the retro-auricular space;

FIG. 5 is a functional block diagram of the microphone module of the present invention;

FIG. 6A illustrates one embodiment of a microphone module of the present invention;

FIG. 6B shows the module of FIG. 6A coated with a steroid or drug; and

FIG. 7 depicts a user wearing a BTE unit behind his left ear.

Corresponding reference characters indicate corresponding components throughout the several views of the drawings.

Detailed Description of the Invention

The following description is of the best mode presently contemplated for carrying out the invention. This description is not to be taken in a limiting sense, but is made merely for the purpose of describing the general principles of the invention. The scope of the invention should be determined with reference to the claims.

Turning first to FIGS. 1 and 2, there is shown a schematic representation of an ear 10 attached to the head 12 of a user of the present invention (or a patient who benefits from use of the present invention). FIG. 1 is a front view of the ear 10, i.e., as seen when looking at the front of the head (i.e., face) of the user, whereas FIG. 2 is a view of the ear 10 as seen when looking at the back of the user's head. The ear 10 has a pinna 20 (a.k.a. auricle) and an ear canal 30. The space behind the pinna 20 is known as the retro-auricular space 50. Advantageously, the retro-auricular space 50 is

generally a hidden space, not readily seen or observed when others look at the user. Disadvantageously, the retro-auricular space 50 is not the best space in which to sense sound waves, at least not with a primary microphone, because the pinna 20 tends to block sound waves from reaching this area.

In accordance with the present invention, a small tunnel 40 is made through soft tissue to connect the retro-auricular space 50 with the ear canal 30. Such tunnel 40 may be referred to as the “ear-canal-to-retro-auricular-space tunnel”. Such tunnel-making is readily accomplished because the tissue is very soft in this region, and the process is medically a relatively simple procedure—being essentially a body-piercing operation. The tunnel 40 need not be very long, e.g., on the order of about 7-25 mm in length, and about 2-6 mm in diameter, depending upon the dimensions of the ear of the patient in whom the tunnel is made.

For purposes of the present invention, the point at which the tunnel 40 opens into the retro-auricular space 50 is referred to as opening 48, and may also be referred to as the “external opening” or the “proximal end” of tunnel 40. Similarly, the point at which tunnel 40 opens into the ear canal 30 is referred to as opening 38, and may also be referred to as the “internal opening”, “ear-canal opening” or “distal end” of the tunnel 40.

As is known in the prior art discussed previously, a hollow tube 44, seen in FIG. 3A, may be implanted in tunnel 40. In accordance with various embodiments of the present invention, such tube implantation may be chronic (intended for a long duration, e.g., permanent) or acute (intended for a short duration, e.g., temporary). The tube 44, when used, keeps the tunnel open and prevents tissue from collapsing or growing back into the tunnel 40. Such tube must be made from a body compatible material, such as Teflon, silicone, ceramic, stainless steel, titanium, or a polymer material. Further, such tube may assume a variety of shapes, e.g., cylindrical, oval, rectangular, or other shape. The tube may further consist of several parts that connect together to allow easy surgical placement, whereby the overall length of the tube may be variable. As discussed in detail presently, all or part of the tube may be hollow.

In accordance with one advantageous embodiment of the invention, and as shown in FIG. 3B, the tube 44 may be coated with a layer 45 of a steroid(s) or other drug(s) adapted to minimize the risk of infection and/or inflammation. As used herein, steroids or drugs include, but are not limited to anti-inflammatories, antibiotics, and other such beneficial drugs and substances. Such steroids or drugs may be encapsulated in a film or coating 45 designed to slowly release the steroids or drugs over a relatively long period of time, e.g., several days or weeks, thereby preventing or minimizing infection and/or inflammation during the time the tissue around the tunnel 40 heals. Representative substances or compounds that may be used to coat the tube in accordance with this aspect of the invention include steroids, or other drugs, either naturally occurring or synthetic, that prevent, minimize, and/or treat infection and/or inflammation.

A microphone module 60, discussed more fully below in conjunction with the description of FIGS. 4, 5, 6A, and 6B, may be inserted into the tube 44 so that a proximal end of the module 60 resides at the opening 48, and a distal end of the module 60 resides at the opening 38. The module 60 is housed in a tubular case that is sized to fit snugly within the tube 44. Advantageously, the module 60 may be readily inserted into, or removed from, the tube 44, thereby allowing the user to replace or remove the module when needed, e.g., to replace or recharge its battery or other power source. Therefore, as used herein, when module 60 is inserted into tube 44, tube 44 becomes a part of microphone module 60, although this may only be temporary.

In other embodiments of the invention, a separate tube 44 need not first be inserted into the ear-canal-to-retro-auricular-space tunnel 40. Rather, the microphone module 60, housed in a tubular case and sized so as to fit snugly within the tunnel 40, may simply be inserted into the tunnel 40, with a proximal end of the module 60 being located at the opening 48 of the tunnel, and with a distal end of the module 60 being positioned at the opening 38 of the tunnel.

Alternatively, tube 44 may be inserted into tunnel 40 temporarily or acutely, e.g., until the tissue has healed and likelihood of infection has passed, at which time, tube 44 may be removed and module 60 inserted. Advantageously, module 60 may be inserted into tube 44 during the time the tissue is healing.

Turning next to FIG. 4, there is shown a back view of the ear 10, as is also shown in FIG. 2, but in FIG. 4 there is a microphone module 60 made in accordance with the present invention inserted into the tunnel 40 (or tube 44, when used), so that a proximal end 62 of the module 60 resides in the retro-auricular space 50, and a distal end of the module 60 (not seen in FIG. 4) is positioned adjacent the distal end 38 of the tunnel 40.

Turning next to FIG. 7, a behind-the-ear (BTE) unit 100 is shown being worn by a user 12 behind his left pinna 20. An ear hook portion 8 may be connected to BTE unit 100 by way of a threadable connection 13, as disclosed, e.g., in the prior referenced '629 patent application. One of the advantages offered by the present invention is that a separate ear hook 8, or other type of ear hook, need not necessarily be used. Rather, BTE unit 100 may attach both mechanically and electrically with a proximal end of the microphone module 60 (which module 60 includes module extension 71, when used) when module 60 is inserted into tunnel 40 or tube 44 within the tunnel, and thereby provide the mechanical support needed to hold BTE unit 100 in the retro-auricular space 50 without a separate ear hook.

Turning next to FIG. 5, there is shown a functional block diagram of a microphone module 60 made in accordance with various embodiments of the present invention. The module 60 is preferably housed or encapsulated within a tubular (or other suitably-shaped) case 61. In some embodiments of the invention and as discussed in more detail presently, an antenna coil 64 is located at an appropriate location within the housing. In some embodiments, the antenna coil 64 may be embedded with the housing material. A microphone 63 is located at a distal end 68 of the module 60. Such microphone comprises a suitable transducer that converts the sensed sound waves 78 into electrical signals.

The electrical signals generated by the microphone 63, in response to sound waves 78 that impinge or strike the microphone 63, are directed to signal processing circuits 67 that are housed within the case 61. Such signal processing circuits 67 may include amplification and filtering circuits that convert and separate the spectrum of signals sensed through the microphone 63 into signals and frequency bands suitable for use by a remote hearing system 79, or may include pre-amplification and filtering circuits that help to preliminarily process the microphone signal prior to sending the signal to the circuits within a BTE unit 100 or other remote hearing system 79. In other words, circuits 67 perform the functions suited to the hearing system of which module 60 is a part. The various functions may be always available in module 60 (so module 60 may work interchangeably with different systems) or modules 60 with specific signal processing circuits 67 may be used, which may reduce the size and complexity of circuits 67 in each module 60. In some such cases, circuits 67 may be included as a part of microphone 63.

Still with reference to FIG. 5, in some embodiments of the invention, the signal processing circuits 67 are connected or coupled to telemetry circuits 69. An antenna coil 64 is also connected to the telemetry circuits 69. The electrical signals received from the microphone 63, and as processed by the signal processing circuits 67, may optionally be presented to the telemetry circuits 69. The telemetry circuits 69 typically modulate an appropriate carrier signal with the processed microphone signals so that the informational content of the processed microphone signals may be transmitted, through antenna 64, to the hearing system 79, which hearing system may comprise BTE unit 100. Such transmission is represented in FIG. 5 by wavy arrows 76 and 76', respectively. In a preferred embodiment, the transmission is by way of an RF link. The wavy arrow 76 thus represents a wireless link 76 with a remote device 79 (such as link 76' with BTE 100) containing a receiver and, optionally, a transmitter.

When the signals are sent to a remote hearing system 79 (e.g., headpiece, BTE, external controller, implant), they may be sent via the wireless communication link 76 established through telemetry circuits 69 and

antenna 64 contained within module 60. An optional cable 90 may also/instead be used. Hearing system 79 is "remote" (as are other “remote” devices discussed herein) in the sense that it is not at the same physical location as microphone module 60, i.e., it is not within ear-canal-to-retro-auricular-space tunnel 40. Hearing system 79, for most applications of the present invention, will comprise a hearing aid system or a cochlear implant system. Signals sent to a BTE 100 may instead be sent, for instance, via connectors 72 and 72a, via cable 90, and possibly through a module extension 71.

As also seen in FIG. 5, the microphone module 60 may, in some embodiments, also include a power source 66. Such power source 66 may comprise a primary battery, a rechargeable battery, or other suitable replenishable power source, such as a super capacitor.

Additionally, a connector assembly 72 is located at a proximal end of the module 60, if needed or desired. Such connector assembly 72 allows additional components to be attached to the proximal end of the module, such as a second microphone (not shown in FIG. 5), an extension module 71, and/or a BTE unit 100, e.g., via a similar connector 72a, as shown in FIG. 5. For instance, when BTE unit 100 is connected to module 60, BTE unit 100 becomes, in effect, a proximal extension of microphone module 60. Another way of looking at it is that when BTE unit 100 is connected to microphone module 60, the microphone module 60 becomes an insertable extension of BTE unit 100. Either way, when BTE unit 100 and microphone module 60 are connected together, they become an effective system or component of a hearing aid delivery system.

As mentioned earlier, an alternative way of connecting BTE 100 to module 60 is by way of a flexible cable 90 (shown with phantom lines in FIG. 5). A first end of such cable 90 connects to connector 72 at the proximal end of microphone module 60. A second end of cable 90 connects to the connector 72a that is part of BTE unit 100. When cable 90 is thus used, only an electrical connection is established between BTE unit 100 and module 60, thus necessitating other means, e.g., an ear hook, for holding BTE unit 100 in the retro-auricular space.

In yet additional embodiments of the invention, cable 90 may extend to another remote device(s), such as an in-the-pocket hearing aid, a headpiece, and/or an external processor or controller, such as a computer configured to interface with the microphone module for programming or diagnostic purposes. Additionally, connector assembly 72 may provide direct connection to the power source 66 for recharging or replenishing purposes.

Advantageously, BTE unit 100 (or other hearing system component, such as a headpiece or extension module) may include a second microphone, and additional microphones may be provided, as mentioned above. A second microphone (and other additional microphones), when used, advantageously permit beam forming to occur, i.e., allow the signals from the primary microphone 63 and any additional microphone(s) to be processed simultaneously, so that the user can better ascertain directional attributes associated with the sound waves that are perceived.

Connector assembly 72, case 61, and/or extension module 71 may include user controls 73, 74 permitting the user of microphone module 60 to make manual adjustments to select parameters associated with operation of the module, e.g., volume, frequency content, and the like. Extension module 71, when used, allows the user to optionally attach additional components to microphone module 60, including additional user controls.

When microphone module 60 is used in conjunction with a BTE unit 100, such controls may instead be incorporated into the BTE unit for better accessibility, but such controls may also be included within the proximal end of the module. Another preferred manner of providing user control of the hearing system is through a remote control unit 75. Remote control unit 75 may be in wireless communication with module 60 over a telecommunications link 77 and/or with hearing system 79 over link 77' (such as with BTE 100 via link 77"). Remote control unit 75 may send signals to, and/or receive signals from, module 60 and/or hearing system 79 (such as BTE unit 100). Over such link 77/77'/77", the user may adjust selected parameters of the module and/or hearing system, and/or program the module and/or hearing system to perform in accordance with a desired or selected signal processing strategy.

Again, connector 72 further allows additional devices or components, other than the BTE unit 100, to be connected to the module 60, thereby forming extensions of the module 60. Such additional components may include one or more additional microphones, a supplemental battery or power source, or user-accessible adjustment controls. Such extensions may, in some embodiments, comprises a feedthrough extension which still allows the BTE unit 100 to be connected to a proximal end of the extension.

As indicated above, the telemetry circuitry 69 is coupled through antenna 64 with the remote unit 75 by way of a suitable telecommunications link 77, e.g., a radio frequency (RF) link. A similar link 77" may, in some embodiments, be established between the remote unit 75 and BTE unit 100, or other hearing system 79, such as a cochlear implant, via similar link 77'. In addition to receiving signals from telemetry circuits 69, remote unit 75 also includes a suitable wireless transmitter for sending a signal to antenna 64 over link 77, thereby permitting bi-directional communication, and also allowing the remote unit 75 to send control and programming signals to module 60. Typically, communications between module 60 and remote unit 75, as well as communications with hearing system 79, employ an RF signal, which RF signal comprises a high frequency RF carrier signal that is modulated by the audio or control/programming information.

Programming features contained within remote unit 75 allow an assistant, or the user, to program the operation of microphone module 60 when first used. Further, additional programming, adjustments, and/or diagnostics of the microphone module may be performed through the remote unit 75, or other device coupled with the module, at any time subsequent to its initial set up.

Control or programming signals received through antenna 64 from remote unit 75 are processed in an appropriate manner, e.g., amplified, demodulated, and conditioned, by circuitry contained within telemetry circuits 69. Such signals are then used to set operational parameters within the signal processing circuits 67 or telemetry circuits 69 so that the circuits within the microphone module perform in a desired fashion. As mentioned

earlier, module 60 may provide and/or supplement the functions of a hearing system component, e.g., headpiece and/or processor, such as BTE unit 100, thereby eliminating or reducing the bulk or such component(s).

Microphone module 60 is preferably inserted into tunnel 40, or into tube 44, so that the microphone resides at the distal end of the tunnel, i.e., at that end of the tunnel that opens into the ear canal 30. In that way, microphone 63 is actually partially in the ear canal 30, or at least right beside the ear canal, so that sound waves 78 that funnel through the ear canal can readily be sensed by the microphone. Such location is thus an optimum location for a primary microphone — i.e., a location where it is able to pick up sounds traveling through the ear canal without obstructing the ear canal.

In some embodiments, sounds spoken by the user may also be sensed by the microphone 63, when turned on, be amplified and processed by the sound and signal processing circuits 67, be presented to the telemetry circuits 69, and transmitted to hearing system 79, thereby aiding the user to "hear" himself or herself. In various embodiment, sounds spoken by the user may be sensed by the microphone 63, when turned on, be amplified and processed by the sound and signal processing circuits 67, and be sent via connectors and/or cable to BTE unit 100 or other hearing system 79, thereby aiding the user to "hear" himself or herself. For users who are profoundly deaf, such feedback (being able to hear oneself) can prove invaluable as they continue to improve their verbal communication skills.

In one preferred embodiment, the signals that are sent and received by telemetry circuits 69 are coded in a way that only designated target and source devices can be linked through telemetry links 76, 76', 77, 77', and 77". One RF telecommunications link that may be used to accomplish this goal is known as Bluetooth. A Bluetooth link advantageously has an identification (ID) code for each device incorporated into its protocol.

Turning next to FIG. 6A, a representative packaging scheme for microphone module 60 is illustrated. Case 61 of module 60, in this instance, is tubular in shape. Case 61 may have a ribbed, scored, or otherwise roughened outer side wall, which may be preferable when inserted directly

into tunnel 40, or may have a smooth outer side wall, which may be preferable when inserted into tube 44.

In accordance with some embodiments of the invention, and as shown in FIG. 6B, case 61 may be coated with a layer 45 of a steroid(s) or other drug(s) adapted to minimize risk of infection and/or inflammation. As in the earlier discussion of coating tube 44, the steroid(s) or drug(s) may be embedded in a suitable carrier substance that dissolves over time, thereby eluting or dispensing the drugs or steroids to surrounding tissue over time.

Case 61 has a diameter D sized to fit snugly within tunnel 40 or tube 44. Further, case 61 has a length L such that when module 60 is properly inserted into tunnel 40 or tube 44, the proximal end 62 of module 60 will be located near the proximal end 48 of tunnel 40, and the distal end 68 of module 60 will be near the distal end 38 of tunnel 40. For example, length L may be about 15-20 mm and diameter D may be about 4-6 mm. Case 61 may be made from any suitable material, such as metal, silicone rubber, Silastic, or other suitable polymer that is biocompatible.

For the embodiments illustrated in FIG. 6A and 6B, there are four sub-modules end-to-end inside the tubular case 61. At the proximal end 62 of the module 60 is a connector sub-module 85. The connector sub-module 85 allows external connections to be made with the module. For example, BTE unit 100 may connect directly with the connector sub-module 85, may connect to an extension module 71 that connects to connector sub-module 85, or cable 90 may connect the BTE 100 with the connector sub-module 85, possibly via extension 71. In some embodiments, the connector sub-module 85 may also contain means, e.g., switches or buttons or wheels, that allow the user to make manual adjustments. Further, the connector sub-module facilitates attachment of a proximal extension module 71 to the module 60. Several different types of proximal extension modules may be used, depending upon user needs at a given time. Such extension modules 71 may be readily plugged into, or unplugged from, the microphone module 60 (possibly via optional cable 90) as needed or desired. For example, some versions of extension module 71 may interface with BTE

unit 100, so that the BTE unit plugs into the extension module, rather than (or in addition to being able to be plugged into) the microphone module 60.

In order to facilitate handling of module 60, and in particular to facilitate removing module 60 from tunnel 40 or tube 44, extension module 71 may have a head portion 81. The head portion 81, like the head of a pin or the head of a nail, allows a user to physically grasp the head portion during insertion or removal in order to apply the necessary insertion or removal forces to the module. A dummy extension module (with no electronic circuitry inside) may be plugged into microphone module 60, in one embodiment, for the sole purpose of facilitating such insertion and removal of module 60 from tunnel 40 or tube 44. Alternatively, a head portion 81 may be provided at the proximal end 62 of module 60, for instance, as part of case 61 or connector sub-module 85.

In one embodiment, the antenna 64, or an auxiliary antenna, may be formed in head portion 81 of the module extension 71 or a head portion 81 of connector sub-module 85 or of case 61. In another preferred embodiment, windings 88 of the primary antenna 64, are positioned against the inner wall, or embedded within the wall, of case 61.

In an alternative embodiment, connector sub-module 85 located at the proximal end of module 60, may facilitate a cabled connection of a remote microphone (another "remote" device), such as a microphone carried at another location on the user's body, e.g., clipped to the user's clothing, or a microphone located remotely from the user, e.g., in a classroom setting where a teacher's microphone may be wired to individual desks throughout the classroom. Connector sub-module 85 may also serve as an input to an external signal source, such as an AM/FM radio, an intercom, a CD player, etc. Such a connector may further serve the function of connector 72 shown in FIG. 5, i.e., as an input to an external power source. (Alternatively, telemetry circuits 69 may be used for such input.) In these ways, the connector sub-module 85, with its connector 72, facilitates extending microphone module 60 to the environment surrounding the user. When used, extension module 71 and/or BTE unit 100 may also/instead provide these connection means.

At distal end 68 of case 61 of microphone module 60 is a microphone sub-module 82. Microphone sub-module 82 contains at least one microphone 63, which may also contain electronic processing circuits, e.g., an impedance transformer, or a pre-amplifier, that may be used to preliminarily process electrical signals generated by microphone 63.

An electronic sub-module 83 and a power source sub-module 84 fill the remaining space within case 61, when needed and/or desired. The electronic sub-module includes the signal processing circuits 67 and telemetry circuits 69. The power source sub-module 84 includes a suitable power source 66, such as a rechargeable battery and/or super capacitor, and associated charging/replenishing circuitry. The charging/replenishing circuitry may, in some embodiments, be found in electronic sub-module 83 rather than within power source sub-module 84. As mentioned earlier, power source 66 may be recharged inductively through the case 61 of module 60. The power source 66 may comprise a rechargeable battery of the same or similar type as is disclosed, e.g., in U.S. Patents 6,185,452; 6,164,284; and/or 6,208,894, which patents are incorporated herein by reference.

In some embodiments of the invention, where microphone module 60 is intended solely for use with a BTE unit 100 or equivalent external device having its own power source, a power source sub-module 84 need not be (but could be or not, as desired) included within the microphone module 60. In such embodiments, the sub-modules within the microphone module requiring operating power receive such operating power from the BTE or other unit's power source.

While the invention herein disclosed has been described by means of specific embodiments and applications thereof, numerous modifications and variations could be made thereto by those skilled in the art without departing from the scope of the invention set forth in the claims.

CLAIMS

What is claimed is:

1. A microphone module (60) for use with a hearing system and adapted for insertion into a tunnel (40) that connects a retro-auricular space (50) to an ear canal (30), comprising:

a case (61) having a proximal end (62) and a distal end (68), which proximal end is configured to be positioned at or near the retro-auricular end of the tunnel, while the distal end is configured to be positioned at or near the ear canal end of the tunnel; and

a microphone (63) housed at the distal end of said case, which microphone is adapted for positioning in or near the ear canal, and which generates electrical signals in response to sensed sound waves (78), which signals are provided to the hearing system.

2. The microphone module of Claim 1 further comprising electronic circuitry (67) housed in said case and electrically connected to said microphone, which electronic circuitry includes signal processing means for processing the electrical signals generated by said microphone in response to sensed sound waves and for providing such processed signals to the hearing system.

3. The microphone module of Claim 2 further comprising:

a telemetry circuit (69) housed in said case and electrically connected to said electronic circuitry;

an antenna (64) connected to the telemetry circuit; and

wherein the telemetry circuit includes means for transmitting a wireless signal representative of the sound waves sensed by the microphone and the signals produced by the signal processing means and for transmitting said wireless signal through the antenna to a remote device.

4. The microphone module of Claim 2 further comprising a connector (72) electrically connected to said electronic circuitry, which connector allows transmission of the processed signals produced by the signal processing means to a remote device.

5. The microphone module of either Claim 3 or 4 wherein the remote device is at least one of a behind-the-ear (BTE) unit, a headpiece, an implanted portion of a hearing system, an external processor, an external controller, an external programmer, an external power source, a remote signal source, and an additional microphone.

6. The microphone module of Claim 5 wherein a BTE unit is physically and electrically connected to the connector.

7. The microphone module of any of the preceding claims further comprising a power source (66) housed in said case and connected to the electronic circuitry, wherein said power source provides operating power for the electronic circuitry housed in said case.

8. The microphone module of Claim 7 wherein the power source comprises at least one of a replaceable primary battery, a rechargeable battery, and a super capacitor.

9. The microphone module of any of the preceding claims further comprising a tube (44) adapted for insertion into the tunnel (40), and wherein the case (61) of the microphone module is adapted to be slidably inserted into said tube.

10. The microphone module of any of the preceding claims further including an extension (71) to the microphone module positioned at a proximal end thereof.

11. The microphone module of any of the preceding claims wherein the hearing system comprises a cochlear implant system having at least a portion thereof implanted in the user.

12. A method of aiding the hearing function of a user, comprising:

providing a microphone module of any of the preceding claims to a user of a hearing system;

supporting the microphone module in a tunnel from a retro-auricular space to an ear canal of the user so a microphone of the microphone module is positioned at or near the ear canal of the user;

sensing sound signals at the microphone;

generating electrical signals in response to the sensed sound waves;

transmitting the signals from the microphone module to the hearing system.

13. The method of Claim 12 further comprising physically and electrically attaching a behind-the-ear (BTE) processor to a proximal end of the microphone module.

14. The method of Claim 12 wherein the step of transmitting signals comprises transmitting RF signals from the microphone module to a remote hearing system device.

15. The method of Claim 12 wherein the step of transmitting signals comprises transmitting signals from the microphone module to a remote hearing system device via a cable.

16. The method of any of Claims 12 through 15 further comprising powering the microphone module with a power source positioned within the microphone module, which power source is at least one of a replaceable primary battery, a rechargeable battery, and a super capacitor.

17. The method of Claim 16 further comprising recharging a rechargeable power source via inductive coupling through a case of the microphone module.

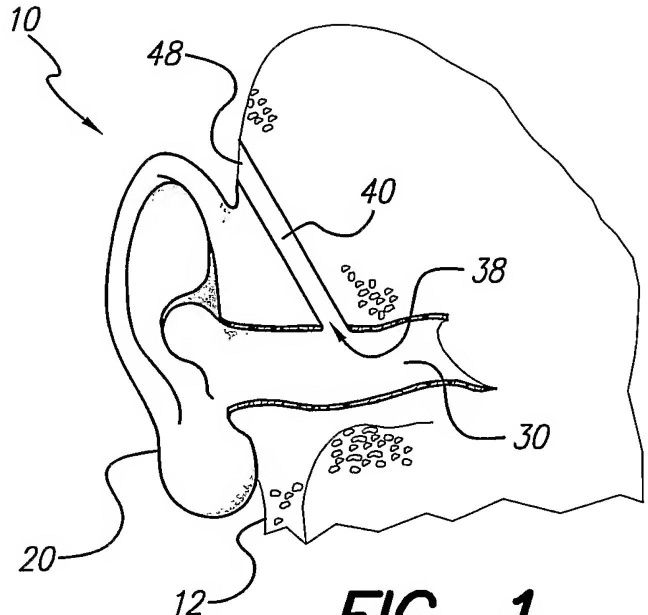


FIG. 1

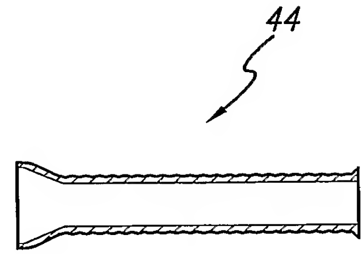


FIG. 3A

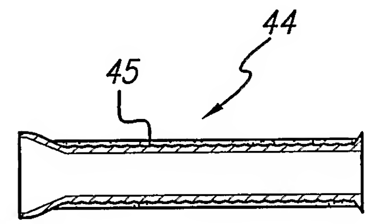


FIG. 3B

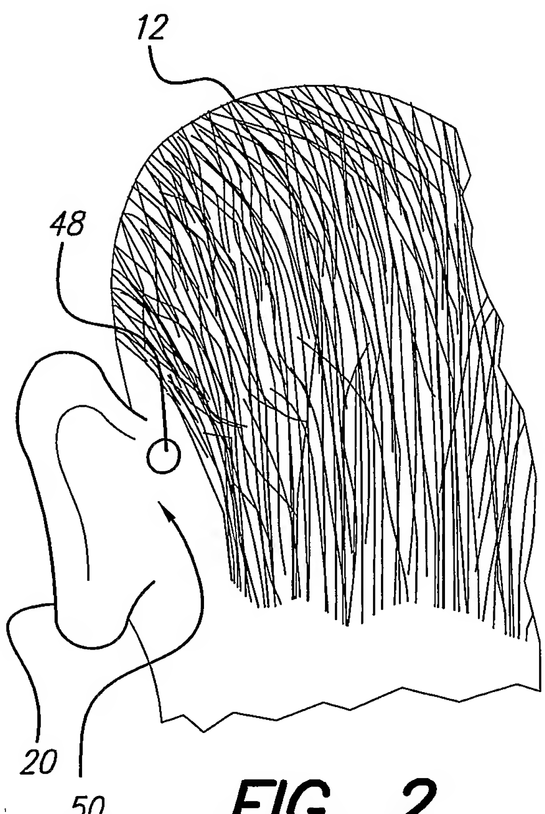


FIG. 2

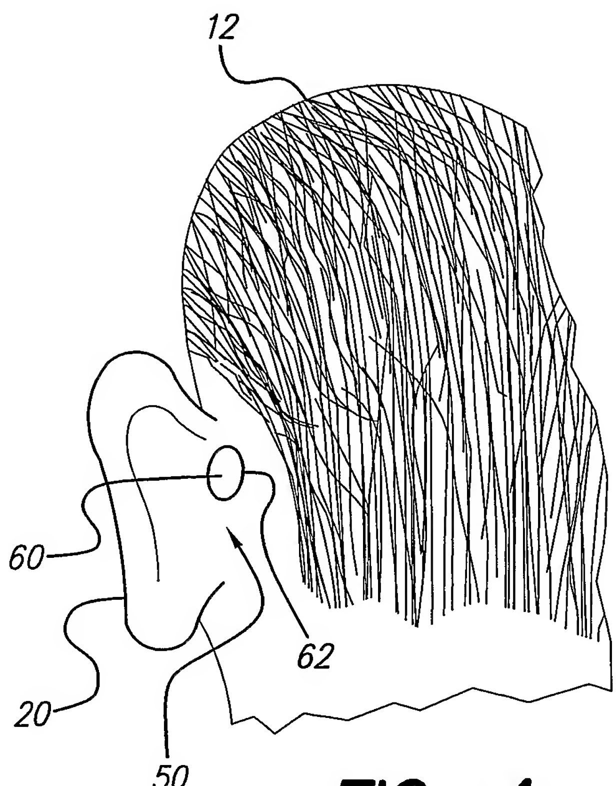


FIG. 4

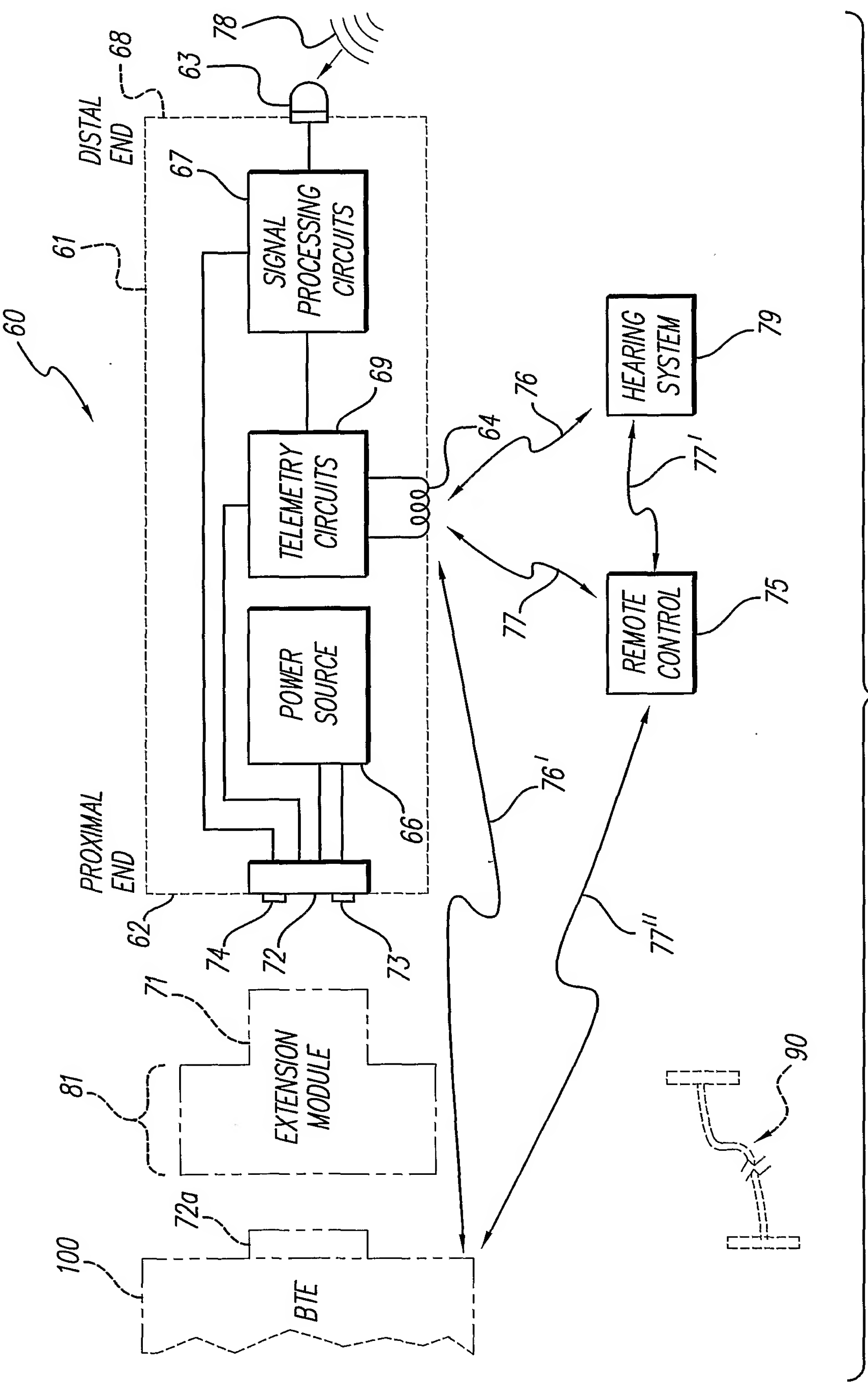

60
61
68
DISTAL END
63
78
67
SIGNAL PROCESSING CIRCUITS
69
TELEMETRY CIRCUITS
64
76
HEARING SYSTEM
79
77'
77
REMOTE CONTROL
75
POWER SOURCE
66
76'
PROXIMAL END
62
74
72
73
77''
71
EXTENSION MODULE
81
72a
100
BTE
90

FIG. 5

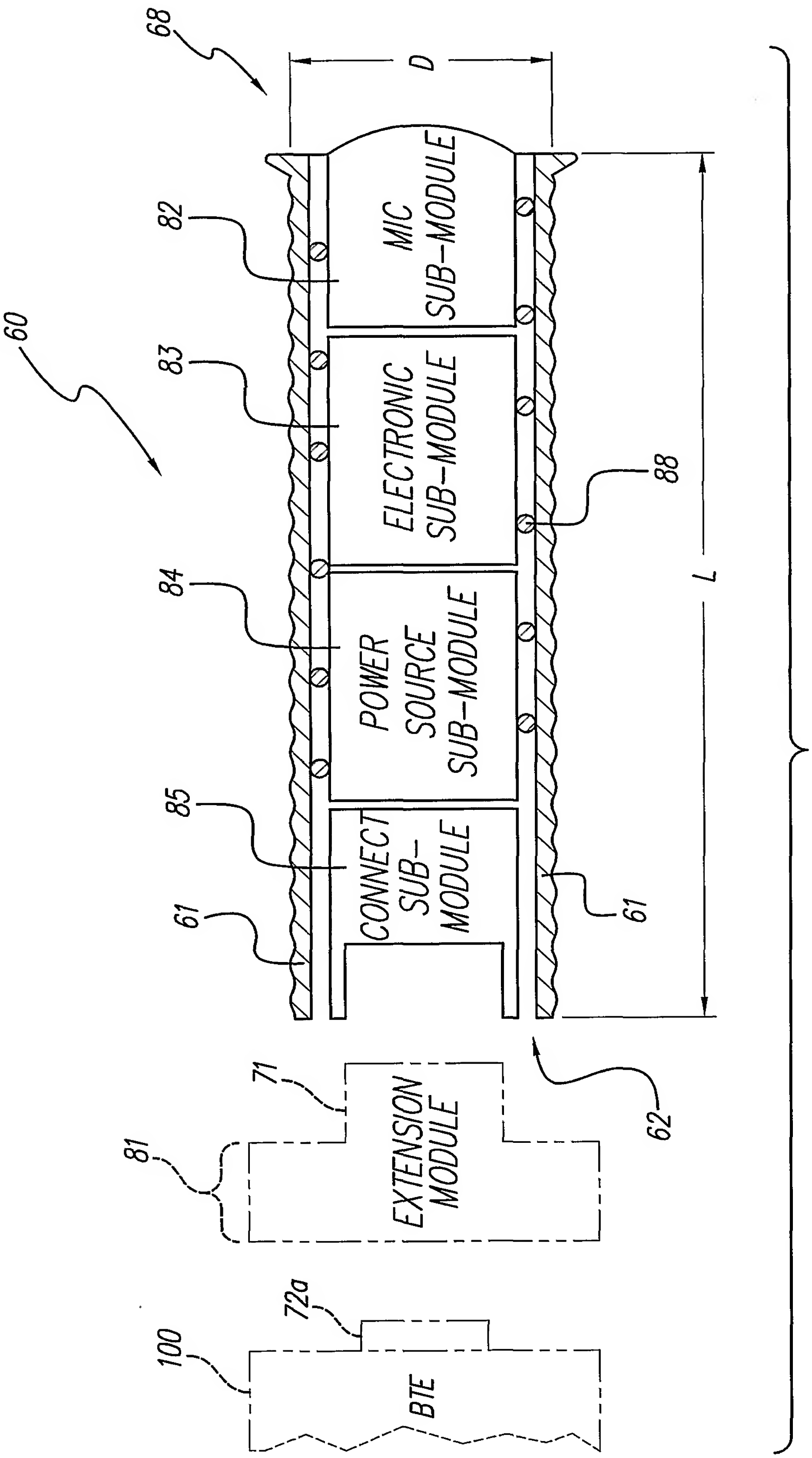
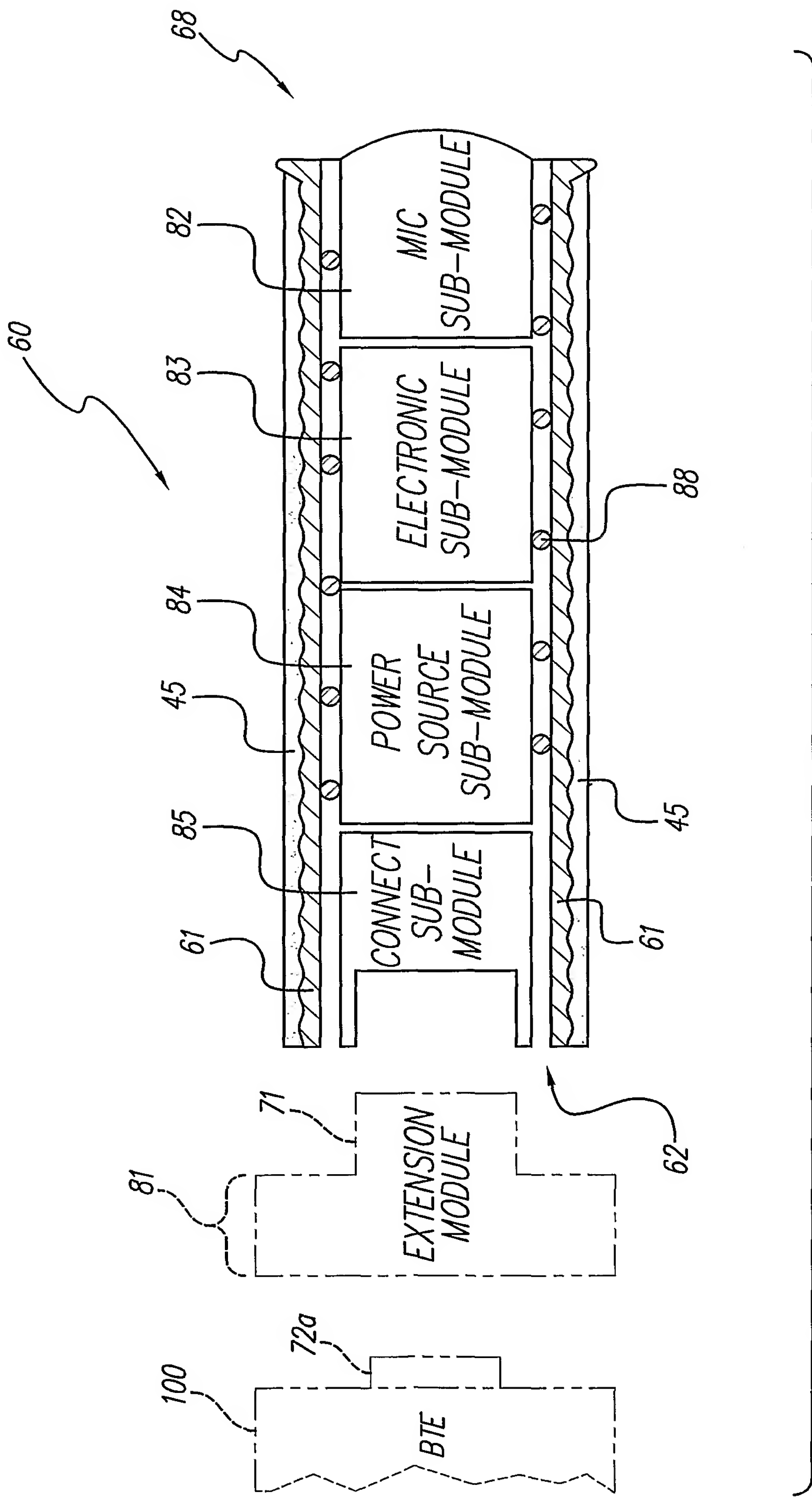

68
D
60
82
MIC SUB-MODULE
83
ELECTRONIC SUB-MODULE
88
84
POWER SOURCE SUB-MODULE
85
CONNECT SUB-MODULE
61
61
L
62
71
81
EXTENSION MODULE
72a
100
BTE

FIG. 6A


68
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ELECTRONIC SUB-MODULE
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88
45
61
62
71
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EXTENSION MODULE
72a
100
BTE

FIG. 6B

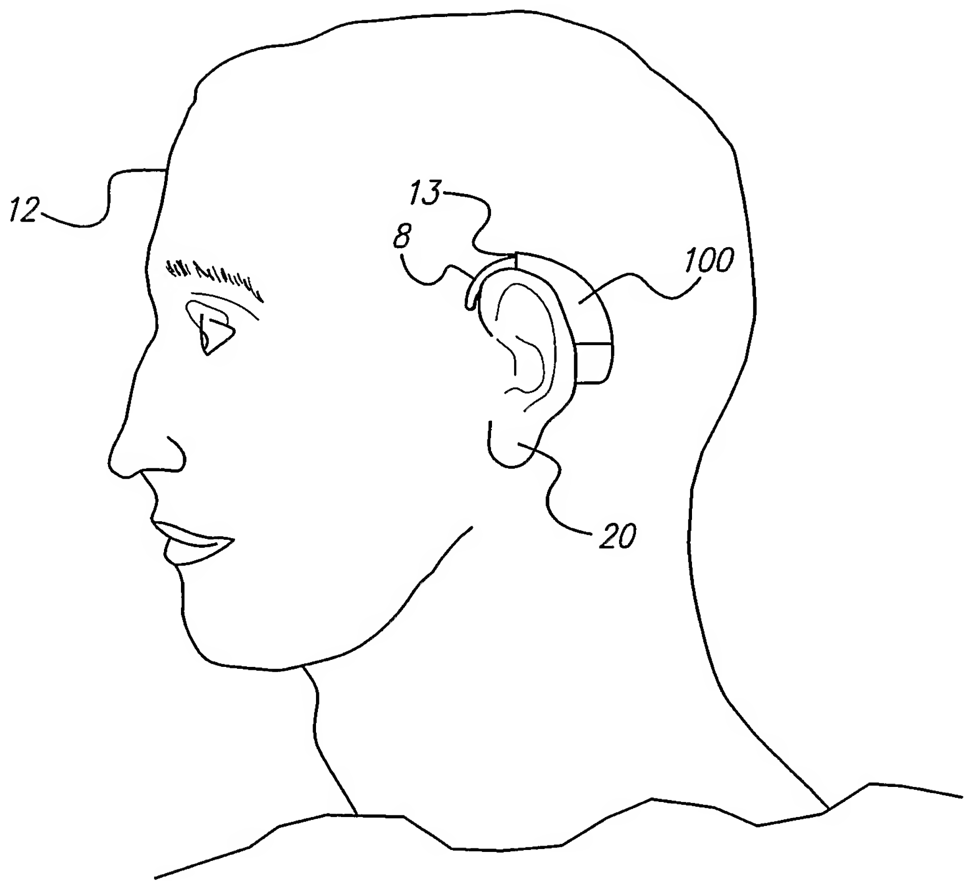

FIG. 7